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THE ANCIENT GLACIERS OF THE ROCKY MOUNTAINS.

BY ARCHIBALD GEIKIE, F.R.S.¹

AMONG the many profoundly interesting questions in American Quaternary geology, one of the most important is unquestionably the determination of the area and movements of the ice during the glacial period. In the Eastern States much has now been done towards the elucidation of this problem. The general southern limits of the great ice sheet, and its course from Canada southwards have been more or less definitely fixed; though much remains to be done before our knowledge even on these points can be regarded as more than a mere outline of the truth. When, however, we try to realize the relations of the ice-sheet westward of the Mississippi basin, we soon perceive the meagreness of our information in regard to these vast western regions. But it is there that one of the most remarkable parts of the glacial problem must be solved. The important labors of Dr. Percival and Profs. Whitney, Irving and Chamberlain, have shown that even within the area embraced by the northern ice-sheet, there was a tract of about 12,000 square miles in Wisconsin that escaped glaciation. Prof. Irving points out that this tract does not owe its immunity from glacial drift to its being higher than the surrounding ground; on the contrary, it is actually lower than the ice-ridden region in Minnesota to the west of it. He supposes it to have escaped because it lay between deep depressions leading out of Lake Superior, by which the great mass of ice, filling that basin, moved off to the south. If this be the true explanation, and it bears strong evidence of probability,

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the ice-sheet must evidently have become considerably attenuated in the Wisconsin region, though still retaining momentum sufficient to carry it down the Mississippi valley into Missouri and Kansas. In Dr. Aughey's recent interesting volume on Nebraska, the extension of the ice westward into that State is clearly proved, and the ice-movement is there shown to have taken a south-south-east direction, or down the Missouri valley. No doubt the glacier had thinned away greatly in that region. Its south-western and western margin, however, remains to be traced up the plains watered by the Missouri. And the day is probably not far distant when the work so well done by Mr. Dawson, in British Columbia, will be prolonged into the Missouri region, and the precise limits and course of the ice-sheet will be mapped across the whole breadth of the continent.

Subsequent explorations have amply confirmed the original observation of Prof. Whitney as to the driftless nature of the surface of the vast interior region lying between the Missouri valley and the Sierra Nevada. The fact may seem almost incredible that the low ground of Eastern North America should have been buried under a southward-creeping ice-sheet, from which the lofty plateaux of the West remained free. The cause of this difference was probably meteorological, as Prof. Dana had pointed out, the snow-fall over the Rocky mountains and western ranges having been insufficient to give birth to a general ice-sheet descending from those heights into the plains. But the question remains: what was the probable condition of the West during the time when glaciation in the East was at its height? We must remember that a considerable portion of the ground through which the drainage of the western plateaux and mountains now reaches the sea, was then blocked up with ice. The valley of the Missouri with all its tributaries on the right down into Kansas, was under ice. Any water-drainage from the west would be ponded back by the great tongue of ice that crept continuously southward from British America, and would no doubt flow parallel with the ice and join the streams, escaping from its melting end. I am not aware, however, that any evidence of such arrest of drainage has yet been met with, though it is a point deserving of attention.

That the mountain ranges of the West had their glaciers, is now well known. Even at the present time, as Mr. Clarence

King announced in 1871, there are true glaciers in the Sierra Nevada, and Dr. Hayden's Survey has more recently found others among the Wind River range in the Rocky mountains. But during glacial times the quantity of snow and ice in some of these uplands, was enormous. In the Uintah mountains the traces of vanished glaciers are singularly fresh. Beautiful horse-shoe-shaped morainal-mounds, occurring far down the valleys, mark pauses in this final retreat of the ice. These have been well described by Mr. S. F. Emmons and Mr. Clarence King, whose narrative I can fully confirm from my own observations. In the Wasatch mountains, also, as the same observers have shown, some of the principal valleys were occupied by glaciers. I was particularly struck by this proof of glaciation in the region of the Cottonwood cañons. At the mouth of the gorge of the Little Cottonwood stream, a pile of morainal-heaps lies on the edge of the highest of the series of ancient terraces of Great Salt lake. There can be little doubt that at the time of the greatest extension of this sheet of water, when filling the vast basin named Lake Bonneville by Mr. Gilbert, it escaped by a northern out-flow into the Snake river and the Pacific, glaciers crept down the valleys on its eastern side, and in one case, at least, advanced into its waters. At this locality the ice descended to within 5000 feet of the present sea level.

But the most startling testimony to the size of the western glaciers, which I met with in the course of a recent journey through these regions, was supplied by the valley of the Yellowstone river. I entered this valley from Fort Ellis, in Montana, a little above the first or lowest cañon. One of the earliest objects to arrest my attention was a prominent rock, like a cottage, in the middle of the alluvial plain. I found it to be a large block of granite measuring $18 \times 12 \times 10$ feet, and weighing upwards of one hundred and fifty tons, which with many smaller erratics lay upon rudely crescent-shaped mounds. There could not be the smallest doubt that these were moraine-heaps, nor that the glacier which carried them must have been very much larger than any of which I had seen traces among the Uintah or Wasatch mountains. The broad valley is here full of moraine-stuff. How much further north the transported material extends, I had no opportunity of ascertaining. But as it is still in full force at the 5000 foot contour line, it evidently descends to a much lower level

than among the Uintah and Wasatch mountains, three hundred and fifty miles further south. Here then was a great glacier moving northwards, while in British Columbia, on a parallel only about two hundred and fifty miles further north, there was a massive ice-sheet moving southward. It will be a point of no little interest to trace these two converging ice streams towards each other.

In ascending the Yellowstone valley towards the National Park, scattered moraine-mounds and abundant transported blocks continue to denote the course and size of the former glacier. I was wholly unprepared, however, for the intense glaciation of the second cañon. This ravine had been cut to a depth of at least eight hundred or one thousand feet in the schists and other older crystalline masses of the region. At its lower entrance a few prominent rocky knobs project from the steep declivity upon the flat alluvium on the left bank of the river. Great was my astonishment to find these spurs of the mountain-side as perfectly smooth, polished and striated as those at the margin of any Swiss or Norwegian glacier. The striæ were directed upward over the ridge, and showed how the ice had been pressed out of the gorge over this opposing barrier of rock. The steep sides of the cañon have been ground smooth and striated in the same way, as far up as I could see, certainly not less than eight hundred feet. Even from below the eye could follow the deep parallel scorings along the ice-worn sheets of gneiss. The glaciation reminded me more of the valley of the lower Aar glacier, above the Grimsel, than of any other European piece of ice-work. As the ice-worn surfaces descend to the modern alluvium of the river, it is clear that there has not been any large amount of erosion in the cañon since the glacier left the scene. I think it is equally certain that the cañon already existed before the glacial period, and that the work of the ice has been to grind it out deeper and wider.

Above the second cañon the moraine-heaps become more abundant and tumultuous. Here and there they enclose small lakes. The tributary valleys too have their moraines and erratics and must have been filled up with ice. Impressive testimony to the magnitude of these ice-masses, is found in that section of the Yellowstone and its surroundings, between Gardiner's river and Mount Washburn. The trail from the Mammoth springs by Blacktail Deer creek, over to the Yellowstone, leads the traveler

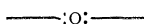
across mounds of glacial débris among which huge boulders of granite and granitoid gneiss are conspicuous. The transported character of these materials is all the more evident from the fact that the platform of solid rock on which they rest often consists of various lavas and other volcanic masses. Some parts of the route present long smooth slopes dotted with boulders precisely like some Scottish boulder-clay moors. The granitic blocks are conspicuous objects even from a distance, owing to their size, a length of six to eight feet being common among them. These signs of glaciation can be traced up to and across the water-shed leading over to the Yellowstone valley. They prove beyond question that not only was that valley filled up with ice, but that the glacier plowed over the ridge one thousand feet above the valley bottom and passed into the country lying to the westward. No old glacier valley in Europe presents a more characteristic scene of ice-drift erratics than does that of the Yellowstone for three miles below Lower falls. The large blocks of granite, gneiss and other crystalline rocks are scattered about so profusely that one might cross the ground for some little distance by leaping from boulder to boulder. The blocks are heaped upon mounds of moraine-stuff, perched on ice-worn hammocks of gneiss, and stream over the horizontal volcanic sheets through which the ravines have been cut.

As the determination of the distribution of the erratics gives an approximate indication of the thickness of the ice, I noted with the aneroid the positions of blocks of granite, gneiss and other non-volcanic rocks on the way up to Mount Washburn, which projects so conspicuously into the valley of the Yellowstone. These blocks get fewer in number and smaller in size as they are followed upwards; but I observed one of three feet long at a height of 8650 feet on the west side of the ridge which rises southward into Mount Washburn, and another about one foot in diameter at a height of 8900 feet. From the position in which these erratics lie, the traveler looks clear over the Yellowstone valley for many miles to the east and west. The general level of the valley-bottom above the edge of the cañon, on the north of Mount Washburn, may be taken at between 6000 and 7000 feet. South from that eminence it rises to more than 8000 feet. The general slope is about 2000 feet in fifteen miles, or roughly, about one hundred and thirty-three feet per mile. The ice, after pass-

ing the barrier of Mount Washburn, cannot have been less than 1650 feet thick (= the height of the three feet boulder on the crest of the ridge), and probably was at least 1900 feet (= the height of the highest observed block). That mountain projecting as a great barrier in the pathway of the ice served to ridge it up, and no doubt partly to deflect it. I observed a granite block south of Dunraven pass, on the south side of the mountain, at a height of 8600 feet, and moraine-stuff and erratics, at intervals, down to the very edge of the Grand cañon, and beyond even as far as the water-shed of the Fire Hole river. Whether Grand cañon existed in glacial times, I found no evidence to prove; but I am inclined to believe that it probably existed only in a rudimentary condition, and has been mainly excavated since that period.

From the evidence here cited, it is clear that the ice of the Yellowstone valley was more than that of a mere local or valley glacier. It was massive enough to fill up the main valley and override the surrounding hills, crossing minor water-sheds and spreading into adjacent drainage basins. From elevated points in the Yellowstone valley, the distant outlines of the Wind River mountain or their northward prolongation can be seen to the south-east, while southward rises the lofty peaks of the Tetons. That these mountains, though not within the present water-drainage basin of the Yellowstone, were within the ice-drainage of the ancient glacier of that valley, is, I think, extremely probable. The abundant blocks of granite and granitoid gneiss lying within the volcanic area of the Upper Yellowstone, seem to have been derived from cliffs outside the basin. Of course I had no opportunity of tracing them to their source. But I could hardly doubt that it will be found in the central archæan cores of these distant mountains. Should this view be confirmed, it will supply an additional proof of the magnitude of these ancient glaciers, for it will show that the snow fields of the Wind River and Teton ranges were so extensive that their ice rivers streamed northward across the buried water-shed, and poured into the basin of the Yellowstone. According to Dr. Endlich, the old glaciers on the west side of the Wind River mountains pushed their way out into the plateau country for several miles, and piled up moraines there to a height of 800 or 900 feet. It is much to be desired by all who take an interest in glacial geology, that an exploration

should be made of the country lying in the Yellowstone valley northward into the area of northern glaciation within the British line. Such a survey will show whether there was any connection between the massive glaciers of the Rocky mountains and the great northern ice-sheet; whether the latter, as it moved down the valley of the Missouri, was swelled by the accession of ice-streams from these mountains. The main facts could be gleaned with comparative ease. The country, no doubt, is the haunt of Crows, Blackfeet, Gros Ventres and other Indian tribes who have recently shown little sympathy with the white man. But this is a difficulty which patience and tact would overcome. The geological harvest is ample, and only waits the advent of some bold and skilled observer.



THE DISCOVERY OF IRON IMPLEMENTS IN AN ANCIENT MINE IN NORTH CAROLINA.

BY FREDERIC W. SIMONDS.

IN Western North Carolina are found many evidences of prehistoric mining operations, such as open cuts, tunnels, shafts and dumps. The latter are covered with a forest growth of several hundred years, and in the excavations has accumulated the débris of centuries.

About ten years ago a new industry was inaugurated in the State, that of mica mining, and strange to say, the best and most profitable mines have been those located upon the sites of the "old diggings." In clearing out the ancient works very few implements have been found which throw light upon the original miners. The opinion, now generally held, is, that they belonged to the Mound-builders, whose mounds are also found, but sparingly, in the river basins. That this is, for the most part, correct, I think has been clearly shown by Prof. Kerr in his Report on the Geology of North Carolina for 1875. He there states that he learned in a conversation with Col. Whittlesey, and subsequently from numerous publications on the subject of the mounds of the Northwest, that mica was of common occurrence in the tumuli of the Mound-builders, among the utensils and ornaments which such rude people are in the habit of inhuming with their dead owners. And upon further inquiry, he ascertained that cut forms, similar to those found in the mounds were occasionally